Investigating the intruder states of ^{83}Se via lifetime measurements

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Abstract. Quadrupole interaction involving protons and neutrons drives the nucleus into deformed configurations at low excitation energies. Intruder states appear in N=49 isotones, reaching a minimum at around 500 keV in ^{83}Se. Since ^{83}Se is in the mid of the proton shell (Z=28-40), it is a good candidate to study the properties of particle-hole intruder states lowered in energy by large quadrupole correlations. Moreover, it will also allow one to estimate the degree of N=50 core breaking in the ground state of Se isotopes. The lifetime of the 540-keV $1/2^+$ state and 1100-keV $3/2^+$ state of ^{83}Se were measured using the Recoil Distance Method and the Doppler Shift Attenuation Method respectively. A beam of ^{82}Se, with intensity 0.02 pnA, accelerated to 270 MeV from the Tandem accelerator at LNL-INFN, was sent into a deuterated polyethylene foil (C_2D_4), evaporated on a 6 mg/cm^2 gold layer. The GALILEO γ-array was coupled to the SPIDER silicon array, allowing one to obtain the needed channel selectivity through particle-γ coincidence measurements.

1. Introduction

The magicity of ^{78}Ni, evidences of shape coexistence, and intruder configurations competing in energy with the spherical ones are very interesting nuclear phenomena appearing in the N≈50 region. In recent years, experimental and theoretical work has been dedicated to explaining several questions concerning the nuclear structure in this region.

The presence of intruder states, which appear as multiparticle-multihole excitation across a closed shell gap, was already known in N=49 isotones. Intruder states with spin $1/2^+$ and $5/2^+$, emerging from the promotion of one neutron from the $g_{9/2}$ orbital across the N=50 shell gap to the $s_{1/2}$ or $d_{5/2}$ shell, were at first seen in ^{83}Se and later in other N=49 isotones [1]. Along

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N=49 isotones, these intruder states become very low in energy reaching the minimum in ^{83}Se, at around 500 keV. Shell model calculations predict even lower energies close to the ground state at variance with the experimental data [2]. Experimental evidences of intruder states close in energy with the spherical configurations were also found in ^{78}Ni [3].

Besides what was already known for the N=49 isotones, a few recent publications pointed out the first evidences of shape coexistence in this region [4, 5]. The spherical shall-gap reduction due to the monopole force lowers the energy of the intruder configurations. Quadrupole correlations affect the intruder configurations in the same way, bringing them closer to the ground state and leading to the appearance of shape coexistence. The comparison of experimental data with theoretical calculations can provide information on the importance of monopole and quadrupole interaction for the occurrence of shape coexistence in this region. The stability of the N=50 shell gap remains yet an open question and more spectroscopic data are needed to get an insight into the amount of the N=50 core breaking.

The ^{83}Se is at the mid of the proton shell which means the quadrupole correlations are at maximum. This makes it a good candidate for understanding the role of the quadrupole correlations in lowering the energy of the intruder states. Lifetime measurements of the intruder state band in ^{83}Se would provide information on the collectivity and on the wave function of these states, helping to estimate the amount of N=50 core breaking for Se isotopes and what to expect towards ^{78}Ni.

2. Experimental setup

A direct reaction in inverse kinematics was used to populate excited states of the nucleus of interest, ^{82}Se(d,p)^{83}Se. A beam of ^{82}Se with an energy of 270 MeV and intensity of 0.02 pnA, accelerated from the Tandem accelerator at Laboratori Nazionali di Legnaro, impinged on a deuterated polyethylene foil (C_2D_4) evaporated on a gold backing 6 mg/cm^2 thick. The target was mounted on a plunger device [6] together with a stopper of ^{197}Au with a thickness of 30 mg/cm^2. The ten days of beamtime allocated to this experiment were shared between two measurements with two different techniques. The Recoil Distance Doppler Shift Method (RDDS) and the Doppler Shift Attenuation Method (DSAM) [7], were used to measure the lifetimes of the intruder states ranging from nanoseconds to femtoseconds.

The Compton-suppressed GALILEO γ-array was used to detect γ rays [8]. GALILEO in the phase II configuration consists of 50 HPGe detectors from which: 20 GASP detectors [9] cover 90 degrees and forward angles with respect to the beamline, meanwhile, 30 Euroball HPGe detectors [10] are arranged into triple clusters shielded with BGO crystals covering backward angles as represented in Fig. 1. Gamma rays interacting with the HPGe via Compton and escaping towards the BGO are discarded, reducing significantly the events contributing to the Compton background in the γ spectrum.

To select the γ rays of the nucleus of interest, GALILEO was coupled to SPIDER [11], an array of segmented silicon detectors designed as an ancillary device for γ-ray spectrometers. In this experiment SPIDER was made of seven pad detectors, each divided into 8 segments, and arranged in a cone-like configuration covering angles from 130° to 165° with respect to the beam line. Coincidence measurements between the γ rays and protons coming from the (d,p) reaction allow one to obtain the needed channel selectivity event by event.

3. Results and future perspectives

One of the major problems when performing lifetime measurements of nuclear-excited states is the feeding of the state of interest from higher energy levels. To avoid this contribution, the information on the particle energy and the detection angle from SPIDER can be used. The use of a (d,p) reaction with gating on the energy of the ejectile and hence on the excitation energy of the state of interest, eliminates any influence from feeding transitions. The kinematic line

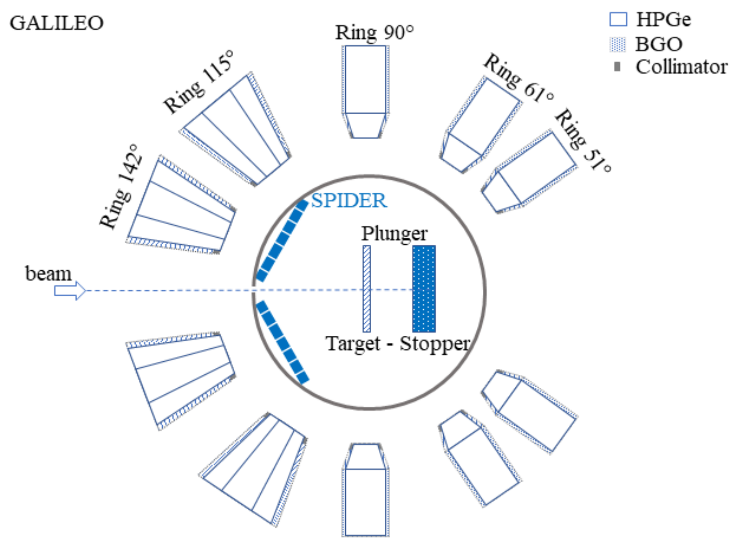

Figure 1. Schematical view of the experimental setup. GALILEO γ-array in phase II coupled to Spider (silicon detector array) and a plunger device for lifetime measurements

of the 540-keV state which decays via 311 keV γ ray is shown in Fig. 2.a. The energy of the protons detected by SPIDER is plotted with respect to the detection angle. As one can see from the figure, the calculated kinematic line (the blue line) with NPTool [12] reproduces the experimental data. After setting a gate in the 2D matrix, the γ-ray spectrum obtained for the forward ring of GALILEO is shown in Fig. 2.b (in the blue color) and compared with the γ-ray spectrum from the same ring when no gates are applied (spectrum in red).

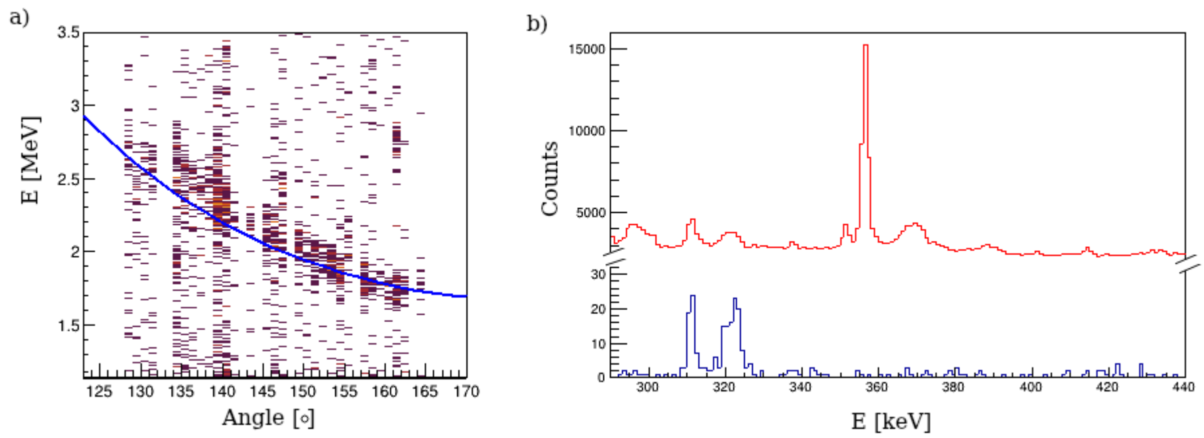

Figure 2. a) The kinematic line of the 540-keV state. SPIDER energy plotted with respect to the detection angle of the proton. The line in blue is the kinematic line calculated from NPTool. b) Comparison of the γ-ray spectrum measured from the forward ring of GALILEO with and without the gate applied on the 2D matrix of the kinematic line

As seen from the figure, the background reduces significantly, and the peak of interest, the 311-keV peak appears in the spectrum. The reaction products, after being produced in the target move towards the stopper with a given velocity. If the nucleus de-excites in flight via

γ decay and if the γ-ray detectors are placed at angles different from 90°, a higher or lower energy will be detected for the corresponding γ ray due to the Doppler effect. The γ peak in the spectrum at around 322 keV arises from the decay in-flight of the state of interest, the 540-keV state. The spectrum shown in the figure corresponds to the 7mm distance between the target and the stopper and was measured by the 51° ring of GALILEO. Measurements were performed for several distances and the ratio of the area of the two peaks, the 311-keV peak and the doppler-shifted peak, will provide information on the lifetime of the 540-keV state.

The lifetime of the 1100-keV state was measured using the DSAM technique. This state decays by emitting γ rays with energy 518 and 560 keV as seen in Fig. 3.a. A gate was set in the 582-keV peak and the spectrum obtained is shown in Fig. 3.b. In the spectrum, the 518-keV peak (indicated with the red line) is seen with a characteristic line shape in lower energy due to the contribution of the decay of the state of interest while slowing down in the stopper. The lifetime will be extracted from the experimental data using realistic GEANT4 simulations which take into account the geometry of the detectors, the reaction mechanism, the kinematics, the response function of the detectors, the decay of the nucleus following complex decay patterns, and the lifetime of the state to be measured. Simulations are performed until the simulated spectrum fits the experimental data and the χ^2 is minimized.

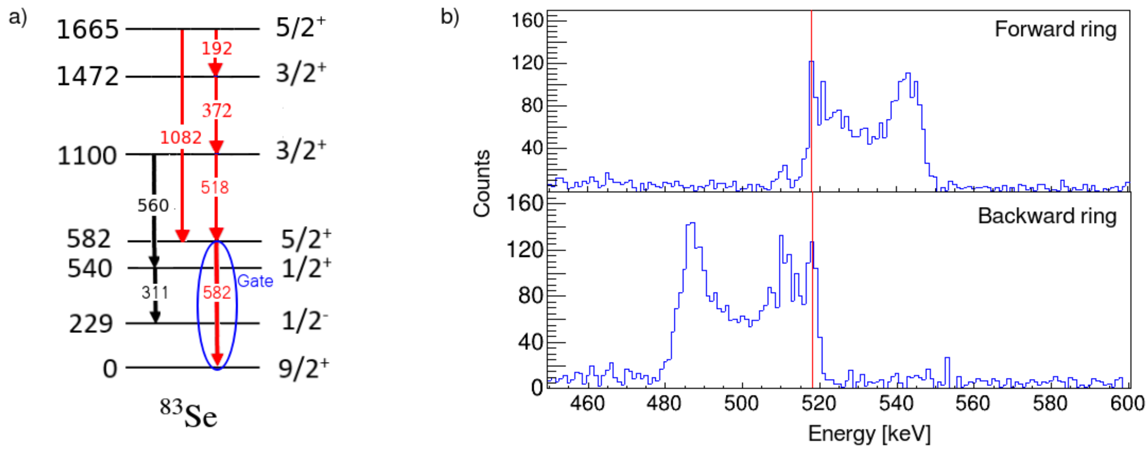

Figure 3. a) Partial level scheme of ^{83}Se. b) Gamma-ray spectrum obtained for the forward and the backward ring of GALILEO after gating in the 582-keV peak. The 518-keV peak (indicated with the red line) shows a characteristic lineshape

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